9th International Symposium on Natural Resources Management

MINERALS · FORESTS · WATER · HUMANS · ENERGIES · ECOLOGY

ZBORNIK RADOVA

BOOK OF PROCEEDINGS

Urednici/Editors:

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Zaječar, 2019.

9. Međunarodni simpozijum o upravljanju prirodnim resursima
9th International Symposium on Natural Resources Management

Izdavač/Publisher:	Faculty of Management, Zajecar, Megatrend University, Belgrade
Za izdavača/For the publisher:	Dragan Ranđelović, Executive Director
Urednici/Editors:	Dragan Mihajlović, Full Professor Bojan Đorđević, Full Professor
Tehnički urednici/Technical editors:	Dragan Jelenković Dragica Stojanović, Assistant Professor
Štampa/Printed:	Printing office "Happy" Zajecar
Tiraž/Copies:	100

ISBN 978-86-7747-606-9

CIP - Katalogizacija u publikaciji
Narodna biblioteka Srbije, Beograd

005:330.15(082)
502.131.1(082)
620.9(082)
338.48(082)

МЕЂУНАРОДНИ симпозијум о управљању природним ресурсима (9 ; 2019 ; Зајечар)
Zbornik radova / 9. međunarodni simpozijum o upravljanju prirodnim resursima, Zaječar, Srbija 2019, 31. maj; [organizatori] Fakultet za menadžment Zaječar, Univerzitet Megatrend [etc.] = Proceedings / 9th International Symposium on Natural Resources Management, Zajecar, Serbia 2019, Masy 31 ; [organizers] Faculty of Management Zajecar, Megatrend University [etc.] ; urednici, editors Dragan Mihajlović, Bojan Đorđević. - Zajecar : Faculty of Management, Megatrend University, Belgrade, 2019 (Zajecar : Happy trend). - 461 str. : graf. prikazi, tabele ; 30 cm

Tiraž 100. - Bibliografija uz svaki rad. - Abstracts.

ISBN 978-86-7747-606-9

а) Природна богатства -- Управљање -- Зборници б) Животна средина -- Одрживи развој -- Зборници в) Енергија -- Коришћење -- Зборници г) Туризам -- Зборници

COBISS.SR-ID 276822796

9. MEĐUNARODNI SIMPOZIJUM O UPRAVLJANJU PRIRODNIM RESURSIMA FINANSIJSKI JE PODRŽAN OD MINISTARSTVA PROSVETE, NAUKE I TEHNOLOŠKOG RAZVOJA REPUBLIKE SRBIJE

9th INTERNATIONAL SYMPOSIUM ON NATURAL RESOURCES MANAGEMENT IS FINANCIALLY SUPPORTED BY THE MINISTRY OF EDUCATION, SCIENCE AND TECHNOLOGICAL DEVELOPMENT OF THE REPUBLIC OF SERBIA

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PREDGOVOR

Kao i prethodnih, i ove godine Fakultet za menadžment u Zaječaru okupio je veliki broj naučnika i stručnjaka sa jednim ciljem – da se ukaže na neprocenjiv značaj prirodnih resursa, kao i na metode i tehnike koje omogućavaju domaćinsko upravljanje njima. Prirodni resursi, neobnovljivi kao i obnovljivi, imaju izuzetan značaj za razvoj određene države. Međutim, rezerve neobnovljivih resursa se neumitno smanjuju, životna sredina izložena je sve većem stepenu zagađenja, i još uvek ne postoji mogućnost zadovoljenja ukupnih potreba za energijom iz obnovljivih izvora. Mnoga pitanja su otvorena, a autori radova koji se nalaze u Zborniku koji je pred vama, pokušali su da daju odgovore na neka od njih. Nadamo se da će čitaoci doći do novih saznanja i generisati nove ideje koje će omogućiti uspešno upravljanje prirodnim resursima u budućnosti.

Zaječar, maj 2019.

Predsednik organizacionog odbora,
Prof. dr Dragan Mihajlović

FOREWORD

This year, the faculty of Management in Zajecar gathers again a great number of scientists and practitioners with one goal – to point out to the invaluable importance of the natural resources, methods, and techniques which enable its responsible managing. Natural resources, non-renewable as well as renewable, are extremely important for the development of a certain country. Besides, the reserves of non-renewable resources are stringently decreasing, the environment is exposed to a high level of pollution, and there is no possibility of satisfying the total need for energy from renewable resources. Many questions arise and the authors whose papers are in the Proceedings which is before you, try to give the answers to some of them. We hope that the readers will come to the new knowledge and generate new ideas which will enable successful natural resource management in the future.

Zajecar, May 2019

President of the Organizing Committee,
Dragan Mihajlovic, Ph.D.

GRINDING CIRCUIT DESIGN SELECTION BASED ON THE OCRA METHOD

IZBOR NAČINA MLEVENJA RUDE PRIMENOM OCRA METODE

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ABSTRACT

One of the phases in the copper ore exploitation refers to ore crushing and grinding of ore. When grinding results of the particles' size are not satisfying, the process must be repeated. Different grinding mills and grinding circuit (GC) designs are at our disposal and it is important to select the appropriate one, responding to the set requirements. For that matter, the authors of this paper proposed the application of the Operational Competitiveness Rating (OCRA) method in this paper.

KEYWORDS

Multiple-Criteria Decision-Making methods, OCRA method, grinding circuit, copper.

REZIME

Jedna od faza eksploatacije rude bakra odnosi se na drobljenje i mlevenje rude. Ukoliko rezultati ove faze nisu zadovoljavajući u pogledu veličine dobijenih čestica, onda navedeni proces mora biti ponovljen. Na raspolaganju su različiti mlinovi i načini mlevenja (GC) te je veoma važno odabrati odgovarajući koji će biti u skladu sa postavljenim zahtevima. U tom cilju, u ovom radu je predložena primena metode pod nazivom Operational Competitiveness Rating (OCRA).

KLJUČNE REČI

Metode višekriterijumskog odlučivanja, OCRA metoda, način mlevenja, bakar.

1. INTRODUCTION

The exploitation of the copper ore implicates a certain number of phases that lead to the final product, i.e. the copper concentrate. Usually, ore contains from 0.5% to 2% of copper and this content could only be lower nowadays because the rich deposits have been exhausted. Due to the low content of valuable minerals, direct smelting of copper ore without previous processing is not economically justified. The production process involves the crushing and grinding of the ore into fine particles, which requires appropriate equipment that is, often, very expensive. Besides, if the process does not result in the particles of the adequate size, the grinding must be repeated.

Various grinding mills have been developed and different grinding circuit (GC) designs with different characteristics and features have been created. When selecting the GC designs, it is important to take into account their features because they would have a significant impact on the process and gained results. Multiple-Criteria Decision-Making (MCDM) methods can be very helpful and applicable when resolving problems of this kind.

MCDM methods represent a very convenient tool for selection of the optimal alternative based on considered criteria. Until now, authors have introduced many different methods, and the best known are AHP (Saaty, 1980), TOPSIS (Hwang, Yoon, 1981), PROMETHEE (Brans, Vincke, 1985), ELECTRE (Roy, 1991) and VIKOR (Opricovic, 1998). These methods have been used to resolve different kind of problems in various fields such as: location selection (Kabir, Sumi, 2014; Chang et al., 2015), project selection (Amiri, 2010), and mining method selection (Bogdanovic et al., 2012; Gupta, Kumar, 2012).

The main goal of this paper is to propose the OCRA method as a suitable technique for selecting the GC design. With that aim, the rest of the paper is organized as follows: section 2 presents the proposed model; section 3 contains the numerical example; in the end, the conclusion is given.

2. THE METHODOLOGY

In this section, we explain the proposed model. First, we present the PIPRECIA method, which will be used to determine the criteria weights. Then, we describe the OCRA method that will be applied in the process of the GC design selectioned.

2.1 The PIPRECIA method

The PIPRECIA method is proposed by Stanujkic et al. (2017) and represents an improvement of the formerly introduced SWARA method (Keršuliene et al., 2010). It is very applicable when defining the criteria weights, especially in the group decision-making environment. The use of the PIPRECIA method can be explained as follows.

***Step* 1.** The evaluation criteria selection. In the case of PIPRECIA method application, pre-sorting of the criteria according to expected importance is not mandatory.

***Step* 2.** Definition of the relative importance s_j, starting from the second criterion, in the following way:

$$s_j = \begin{Bmatrix} >1 & when & C_j \succ C_{j-1} \\ 1 & when & C_j = C_{j-1} \\ <1 & when & C_j \prec C_{j-1} \end{Bmatrix}. \tag{1}$$

***Step* 3.** Determination of the coefficient k_j using the following Eq.:

$$k_j = \begin{Bmatrix} 1 & j=1 \\ 2-s_j & j>1 \end{Bmatrix}. \tag{2}$$

***Step* 4.** Definition of the recalculated value q_j, as follows:

$$q_j = \begin{Bmatrix} 1 & j=1 \\ \dfrac{q_{j-1}}{k_j} & j>1 \end{Bmatrix}. \tag{3}$$

***Step* 5.** Obtaining the relative weights of the evaluation criteria by using the following Eq.:

$$w_j = \frac{q_j}{\sum_{k=1}^{n} q_k}, \tag{4}$$

where w_j is the relative weight of the criterion j.

2.1 The OCRA method

The OCRA method is proposed by Parkan (1994). In upcoming years, the given method has been furtherly improved by various authors, such as Parkan and Wu (1997), and Chatterjee and Chakraborty (2012). In this paper, the computational procedure of the OCRA method relies on the one presented in the paper by Stanujkic et al. (2017) and can be presented by the following steps.

***Step* 1.** Compute the aggregate performance ratings for the cost criteria, using the following Eq.:

$$\bar{I}_i = \sum_{j \in \Omega_{\min}} w_j \frac{\max_j x_{ij} - x_{ij}}{\min_j x_{ij}} \notin [-1,1], \tag{5}$$

where $\bar{I}_i$ represents the aggregate performance rating of the alternative i, obtained on the cost criteria basis, x_{ij} is the performance rating of the alternative i relative to the criterion j and $\Omega_{\min}$ is the set of the cost criteria.

***Step* 2**. Compute the linear performance ratings for the cost criteria, as follows:

$$\bar{\bar{I}}_i = \bar{I}_i - \min_i \bar{I}_i, \tag{6}$$

where $\bar{\bar{I}}_i$ presents the linear performance rating of the alternative i, defined on the cost criteria basis. The zero rating is assigned to the least preferable alternative in the OCRA method, by performing the linear scaling.

***Step* 3**. Compute the aggregate performance ratings relative to the benefit criteria, using the following Eq.:

$$\overline{O}_i = \sum_{j \in \Omega_{\max}} w_j \frac{x_{ij} - \min x_{ij}}{\min_j x_{ij}} \notin [-1,1], \tag{7}$$

where $\overline{O}_i$ is the aggregate performance rating of the alternative i, defined on the benefit criteria basis, and $\Omega_{\max}$ represents the set of the benefit criteria.

***Step* 4.** Compute the linear performance ratings for the benefit criteria, as follows:

$$\overline{\overline{O}}_i = \overline{O}_i - \min_i \overline{O}_i, \tag{8}$$

where $\overline{\overline{O}}_i$ is the linear performance rating of the alternative i, defined on the benefit criteria basis.

***Step* 5.** Compute the overall performance ratings in the following way:

$$P_i = \bar{\bar{I}}_i + \overline{\overline{O}}_i - \min(\bar{\bar{I}}_i + \overline{\overline{O}}_i)\ , \tag{9}$$

where P_i represents the overall performance rating of the alternative i.

3. A NUMERICAL EXAMPLE

This example was originally presented in the paper by Stanujkic et al. (2014) and retrieved for the purpose of showing the proposed method applicability. The three alternative GC designs are involved in the estimation procedure and are shown in **Table 1**.

Table 1. Grinding circuit designs

	Grinding circuit design	*Explanation*
A_1	The first typical grinding circuit design	The ore crushing could be performed in two or three phases
A_2	The second typical grinding circuit design	The grinding process contains one phase which is based on the ball mill
A_3	The third typical grinding circuit design	The grinding process is, mainly, based on using the SAG mill

The criteria which are the base for the evaluation process are depicted in **Table 2**.

Table 2. Evaluation criteria

	Criteria	*Explanation*
C_1	Grinding efficiency	Obtaining the particles of the required size with minimal costs
C_2	Economic efficiency	Minimal operating and maintenance costs
C_3	Capital investment costs	Minimal capital investment costs
C_4	Environmental impact	Minimal impact on the environment as well as minimal energy consumption

As we have already stated, the alternative GC designs, as well as the evaluation criteria, are taken over from Stanujkic et al. (2014). The difference relative to the mentioned paper reflects through the fact that, in this case, only one decision-maker (hereinafter referred to as *DM*) is involved in the evaluation procedure.

We obtained the importance of the considered evaluation criteria using the Eq (1)-(4), presented in **Table 3**.

Table 3. The relative importance of the criteria

Criteria	s_j	k_j	q_j	w_j
C_1		1	1	0.24
C_2	1.00	1.00	1.00	0.24
C_3	1.10	0.90	1.11	0.27
C_4	0.90	1.10	1.01	0.25
			4.12	1.00

As **Table 3** shows, all the considered criteria have nearly the same importance. Only the criterion C_3 – *Capital investment costs* have significantly greater importance relative to the others.

The initial decision matrix is given in **Table 4**. Decision-maker *DM* assessed the alternative GC designs relative to the given criteria by using the 5-point scale. The worst mark is 1 (very poor) and the best is 5 (very high) (Bogdanovic et al., 2012).

Table 4. Initial decision matrix

	C_1	C_2	C_3	C_4
	max	max	min	min
w_j	0.24	0.24	0.27	0.25
A_1	3	2	3	3
A_2	2	3	2	3
A_3	4	3	3	2

The evaluation of the available alternatives is performed using the Eq. (5)-(9) and the obtained results are shown in **Table 5**.

Table 5. The calculation data obtained by using OCRA method

	$\bar{I}_i$	$\bar{\bar{I}}_i$	$\bar{O}_i$	$\bar{\bar{O}}_i$	P_i
A_1	0.0000	0.0000	0.1213	0.0000	0.0000
A_2	0.1348	0.1348	0.1213	0.0000	0.1348
A_3	0.1225	0.1225	0.3640	0.2426	0.3652

The final results and ranking order are depicted in **Table 6**.

Table 6. The ranking order of the alternatives

	P_i	*Rank*
A_1	0.0000	3
A_2	0.1348	2
A_3	0.3652	1

In this case, according to *DM*, the best alternative is alternative A_3, i.e., GC design based on using SAG mills.

4. CONCLUSION

The exploitation of copper ore implies that a certain number of steps should be performed in order to produce considered metal. Before processing, the ore should be crushed and ground, thus prepared for further processing. If the size of the obtained particles is not suitable for further processing, the grinding should be repeated.

There are different kinds of grinding mills as well as CG designs that could be used in the working process. The selection process should be carefully performed, in order to maximize benefits and minimize losses. The final choice should satisfy different requirements, which makes the MCDM methods a suitable way of facilitating the decision-making process in this field.

In this paper, we used the OCRA method for ranking and selection of the GC design. The applicability of the proposed method is shown by using the example from Stanujkic et al. (2014). The obtained results have shown that the optimal choice is alternative A_3, which is also ranked first in the paper by Stanujkic et al. (2014), proving the reliability of the proposed method.

The main deficiency of the paper reflects through the fact that the decision process is entrusted to one *DM* only. Also, the computational procedure is based on the crisp numbers, because of which the uncertainty and vagueness of the environment are not acknowledged in the proper degree. Besides, it would be desirable to increase the number of alternatives, as well as the evaluation criteria. The OCRA method proves that it is very simple to use, reliable and appropriate for the application in the field of the mining exploitation, and the main proposition is to examine its potentials in other business fields.

ACKNOWLEDGMENTS

The paper is a part of a research conducted on the project under the code *TR 33023,* financed by the Ministry of Education, Science and Technological Development of the Republic of Serbia.

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